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INT CL^6 H01J 37/30 37/302 37/305
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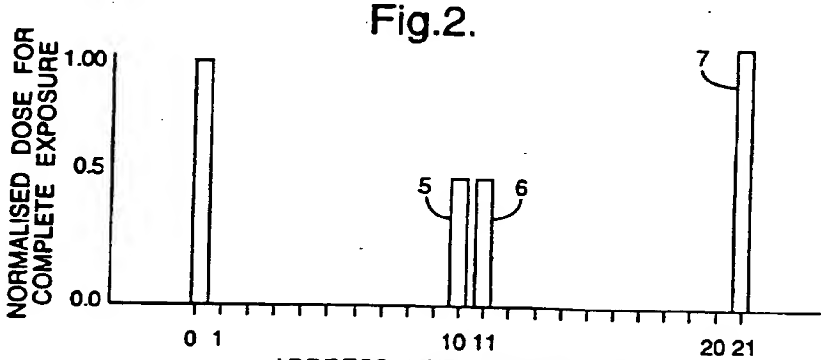
(54) Electron beam scanning system suitable for chirped grating fabrication

(57) The scanning system is particularly suitable for making a chirped grating in an optical, for example fibre, waveguide. In the system effective grating lines are created, at positions which are not available from a scanning address grid, from actual lines created from positions that are available from the scanning address grid.

Fig.2.



GB 2 333 018 A

Fig.1.

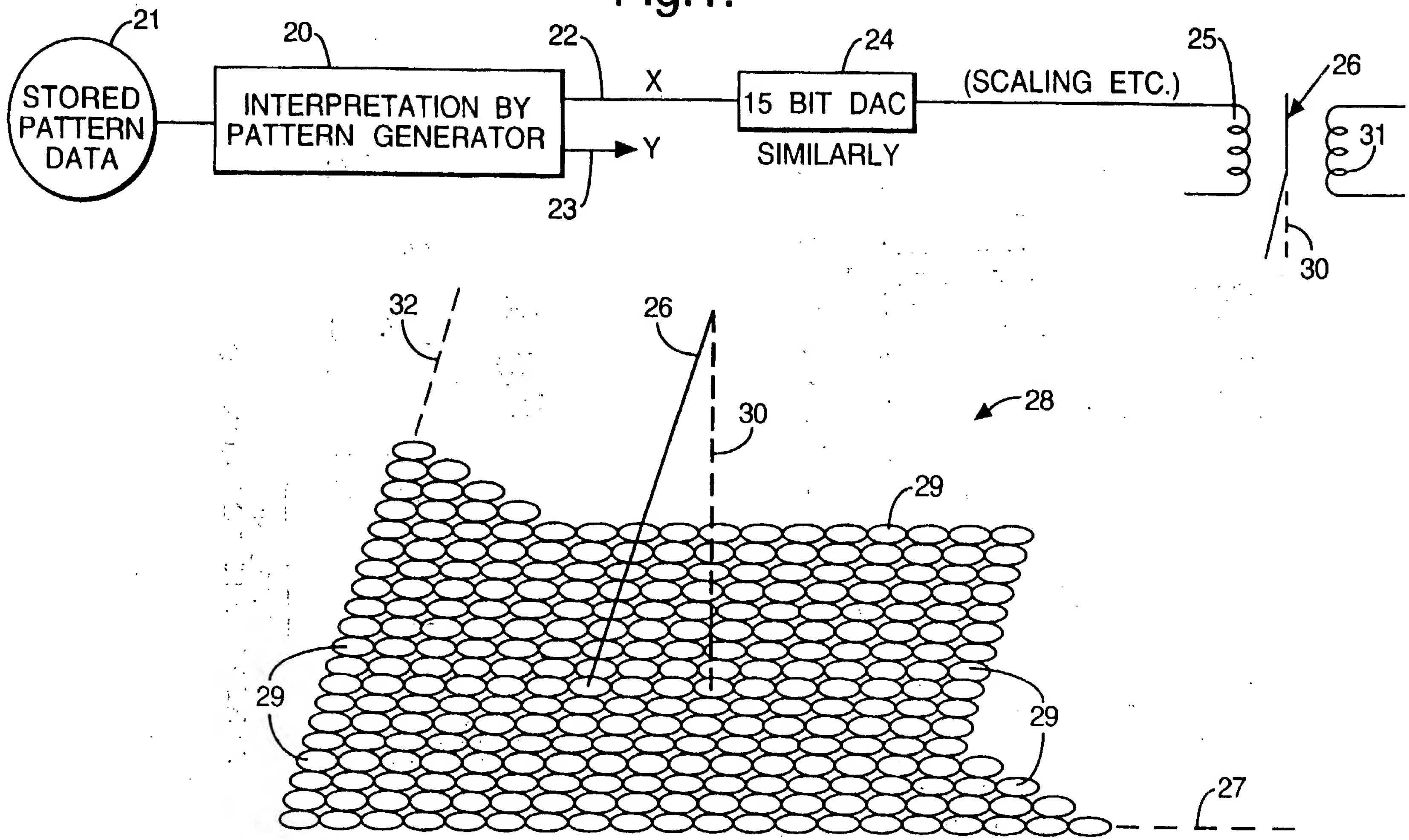

21
STORED PATTERN DATA
20
INTERPRETATION BY PATTERN GENERATOR
22
X
23
Y
24
15 BIT DAC
SIMILARLY
(SCALING ETC.)
25
26
31
30
32
26
30
28
29
29
29
27

Fig.2.

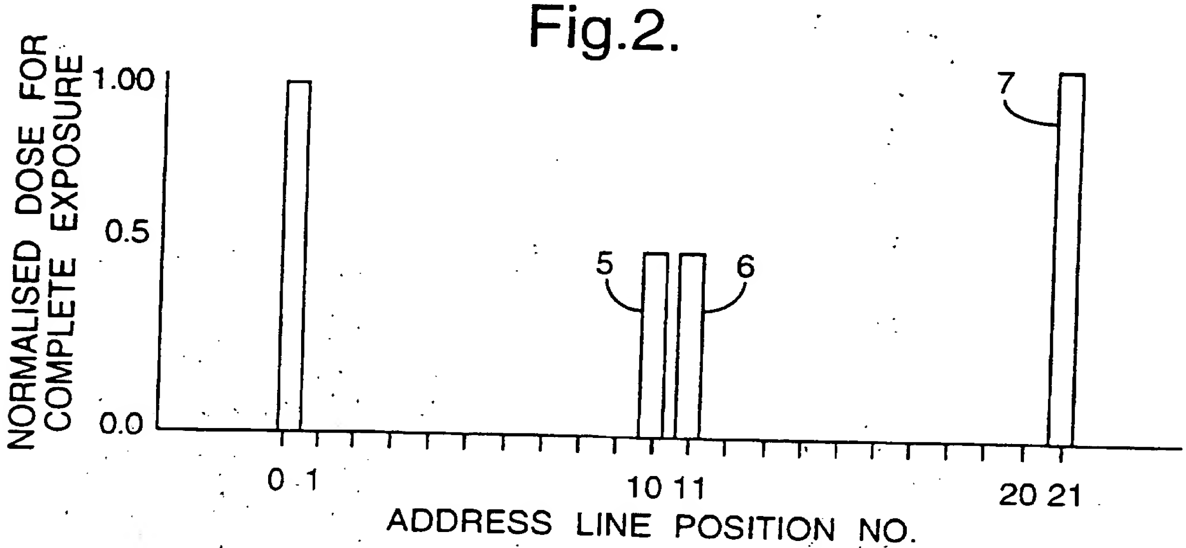

NORMALISED DOSE FOR COMPLETE EXPOSURE
1.00
0.5
0.0
7
5
6
0 1
10 11
20 21
ADDRESS LINE POSITION NO.

Fig.3.

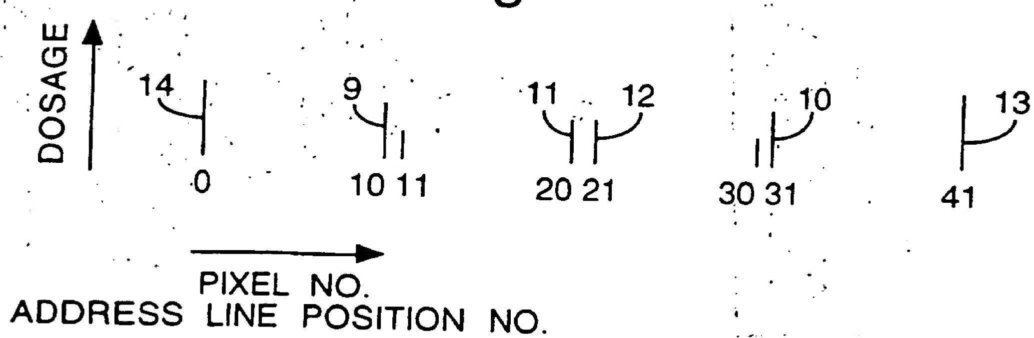
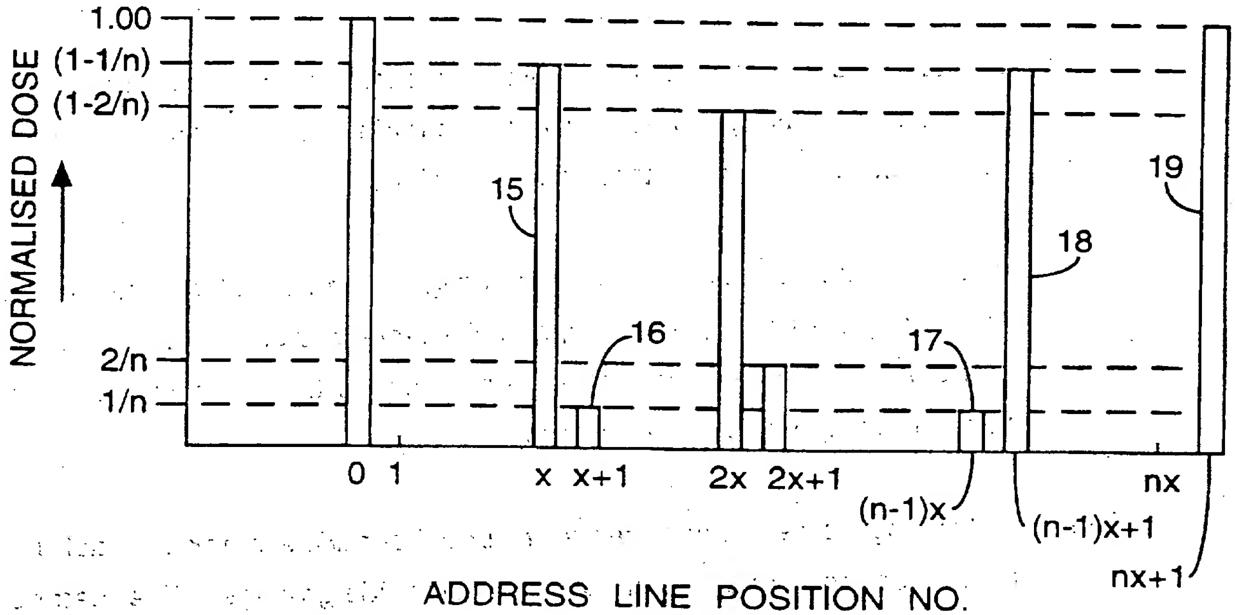

DOSAGE
14
9
11
12
10
13
0
10 11
20 21
30 31
41
PIXEL NO.
ADDRESS LINE POSITION NO.

Fig.4.


1.00
(1-1/n)
(1-2/n)
2/n
1/n
NORMALISED DOSE
15
16
17
18
19
0
1
x
x+1
2x
2x+1
(n-1)x
(n-1)x+1
nx
nx+1
ADDRESS LINE POSITION NO.

SCANNING SYSTEM SUITABLE FOR CHIRPED GRATING FABRICATION

The present invention relates to a scanning system which is particularly, though not exclusively, applicable to a system for use in scanning an area in a series of parallel grating lines to produce a chirped optical waveguide grating.

A method to be described below, by way of example in illustration of the invention, includes making a grating using a scanning address grid which has a much finer address line pitch than the pitch of the grating.

The use of this method makes possible a higher degree of control of the position of grating lines than previously, enabling, *inter alia* comparatively small degrees of chirp and more controllable chirp functions to be provided in, e.g. optical fibre or planar waveguide gratings.

The term "grating" is herein intended to include *inter alia* a blank or mask for use in the production of one or more optical waveguide gratings. The method is not limited to x-y or Cartesian scanning. It can be applied to other systems for scanning areas, e.g. with radial grating lines in a polar scanning system. It is assumed that a scanning address grid can address or command the generation of a grating line at any of a given number of address line positions.

For ease of understanding in the description, except when otherwise indicated, scanning will be assumed to be Cartesian, i.e. along lines parallel to the x-direction and spaced in the y-direction.

For the production of an optical fibre waveguide grating which causes dispersive reflections or diffractive deflections in a wave travelling along the

waveguide, a grating blank or mask is used in one example to be described. A narrow band reflective grating in a fibre is able to act as an external cavity mirror in a laser diode; for stabilizing and narrowing the output wavelength of the laser. Any changes in the grating spacing will have a marked effect on wavelength tuning, so that the precise control of the spacing is of importance. A grating typically consists of a periodic variation in the refractive index of a fibre wall along the axis of a fibre.

A grating mask or blank may be produced on a silica substrate, either optically through a photo-resist process, or by scanning an electron beam. When illuminated by a laser, the grating mask produces a corresponding interference pattern (dependent on the grating spacing and the wavelength of the laser beam), which is to match the desired pattern of grating spacings. A grating may be produced by a single exposure of the grating mask. The method and apparatus to be described below, as an example, enable an optical waveguide equipped with such a grating to be provided.

A method and apparatus for producing an index grating in the core of an optical fibre was proposed in the specification of U.S. Patent No. 5,104,209, issued April 14 1992. In that method, a grating mask in the form of a slit mask containing one or more slits was placed over an optical fibre and the fibre was illuminated through the slit mask by substantially monochromatic ultraviolet light for a short interval.

The method and apparatus to be described below by way of example, enable a grating to be produced more accurately than hitherto with greater flexibility in defining the spacing between grating lines, whether it be fixed or variable.

A previously proposed way of automatically selecting line locations in a diffraction grating, which has parallel lines very close together typically, for example with spacing of the order of one micron or less, and produced by a photographic process, such as photo-lithography, is e.g. to write a grating line

every tenth address line of a scanning address grid. Grating lines may be written with a spacing equal to some other given whole number, say 9 or 11 address lines per grating line position. Then for every 9, 10 or 11 lines of the address grid, the scanning system commands the production of one line of the grating at some standard, constant exposure. With this example the grating line pitch can be varied only by a limited amount, namely by about 10%.

Arrangements to be described below, by way of example in illustration of the invention, provide methods and apparatus by means of which grating lines, which may be uniformly or variably pitched, at one or more spacings which are slightly different from integral numbers of the available address lines may be produced with a higher degree of accuracy and in a more simple manner than previously. Effective grating lines at positions which are unavailable directly from a scanning address grid may be derived from actual lines created at positions that are available from the scanning address grid.

The arrangements to be described below, by way of example, enable the spacing between the lines to be written in a grating to increase and/or to decrease over one or more regions in a direction transverse to the lines. In general such variations in spacing or pitch do not represent changes by a large factor. It is well known to refer to a varying pitch as a "chirp". A grating may have a varying pitch or chirp requiring a very fine control of the selection of the address lines of a scanning address system or grid which is used in writing lines of a grating.

A discussion of previously proposed designs and methods of making chirped gratings may be found in a communication entitled "Novel method of producing all fibre photoinduced chirped gratings" by R. Kashyap et al, in Electronics Letters, Vol. 30 No. 12, June 9 1994 at pages 996-998, and in the literature cited at the end of this communication. This communication acknowledges that chirped fibre gratings may give chromatic dispersion compensation for long-haul communication, and that large or small chirps may be desirable.

The arrangements to be described below by way of example in illustration of the invention provide improved accuracy in the manufacture of optical fibre gratings without recourse to several different scanning address systems for making any necessary masks, and whether or not chirp is required.

Embodiments to be described below, by way of example, in illustration of the invention, feature the reduced, i.e. partial exposure of a grating line at each of at least two successive address lines in a scan, in a graded manner, such that, without altering the scanning address grid, the effective exposure, as far as use as a grating is concerned, is an effectively written desired grating line some way between, or among the two or more of the partially exposed actual grating lines. These two or more partially exposed actual lines will be, as before, at positions determined by scanning lines of the address grid, but the <u>effective</u> exposure will be at a position selectively intermediate two (usually two consecutive) scanning address line positions. Some actual address line positions may correspond with desired effective grating line positions, in which case there will be no partially exposed actual grating line pair coinciding with these address line positions, just the one actual grating line at the desired position. However most of the desired effective grating line positions will be synthesized from groups of two or more actual partially exposed, usually neighbouring, address lines.

Arrangements illustrative of the invention will now be described by way of example with reference to the accompanying drawings, in which:-

Fig. 1 illustrates partly by means of a block schematic circuit diagram and partly by a diagrammatic perspective view an exposure address and scanning system for producing a grating by the control of an electron beam over a matrix of addressable points, in accordance with grating pattern data, and

Figures 2, 3 and 4 are diagrams illustrating dosage, i.e. exposure intensity of actual lines of a pattern as successive desired lines of a grating are effectively

written according to the available lines of a scanning address system controlling e.g. a photographic process, such as photo-lithography, in various embodiments where some at least of the desired grating lines do not coincide with individual available lines of the scanning address grid.

Referring to Fig. 1, a pattern of spaced elements forming a desired grid, perhaps derived from computer aided design is read by an interpreter 20 from a data store 21 and outputted over signal paths 22 and 23 into for example X-component analogue signals and Y-component analogue signals respectively. The grid pattern has been decided upon beforehand, and examples are graphed in Figs. 2, 3 and 4.

Signal paths 22 and 23 feed the X and Y signals to respective digital address coders, one of which is schematically shown at 24. The X address coder 24 drives an X-deflection coil 25 which deflects an irradiation beam 26 in an X-direction from a centre position 30, i.e. parallel to an X-axis 27 of a square matrix 28 of separately addressable beam-sensitive points 29. At each point 29, impingement by the beam 26 forms a trace. The Y-address coder, not shown, drives a Y-deflection coil 31 which deflects the beam 26 in a Y-direction relative to the centre position 30, parallel to a Y-axis 32.

Thus the beam can be deflected in X and/or Y directions to select and impinge on any beam-sensitive point 29 in the square matrix. The matrix consists of rows, each of 2^{15} elements and each row parallel to the X-axis. The rows are also 2^{15} in number and aligned with each other, such that 2^{15} columns of elements 29 are also formed, each column extending in the Y-direction parallel to the Y-axis 32. Each 15 bit address from digital address coder 24 thus selects a row of elements 29, and each 15-bit address from the other coder (not shown) selects one element in that row.

Thus if grid lines are assumed to be parallel and to extend in the Y-direction, they will be spaced in the X-direction. The minimum spacing available in the

X-direction will be the width of each element, so that actual lines can relatively easily be traced at the X-coordinate of each column of elements 29, where there are available addressable points.

If it is desired to trace grid lines along Y-direction lines <u>between</u> two columns of elements 29, there will be no available elements to trace actual grid lines or elements. By the teaching of the present invention, each unavailable but desired line is created effectively by two (or more) actual grid lines corresponding to actual columns of addressable points 29 each actual grid line having less than a standard dose. The elements 29 are such that the intensity of the trace depends on the dose or current of the beam impacting the column of points 29. The selection of actual grid line positions to create desired effective line positions will be further explained with reference to Figs. 2-4.

Figure 2 is a graph of amplitude against scanning address grid line number, and illustrates increasing an effective line scan pitch by 0.5 address lines (i.e. not an integral number of lines).

Referring to Figure 2, it is desired to write effective grating lines with a spatial period, i.e. a spacing of 10.5 times the scanning spacing resulting from an available source of lines in a scanning address grid. If it were desired to write grating lines with spacings of 10, 11 or 9 or 13 address line spacings, one of the arrangements described with reference to Figure 1C for areas 1.1, 1.2 and 1.3 would be used. However, it is desired to use the same available scanning source, and to write effective lines at desired locations every 10.5 address lines. Thus some lines will have effective positions that do not coincide with an address line.

Figure 2 uses the zero number, i.e. 0th line or other address grid line as a datum, and at this 0th grid line, one full exposure is made, in that a whole irradiation dose of some value is utilized to write a first grating line at a desired position on a grating substrate (not shown). This first line is an actual line, and

an effective grating line, as will be seen. At the tenth address line after this datum, and referenced 5 in Figure 2, an approximately half dose exposure is made, and a similarly approximate half dose referenced 6 is exposed at the 11th address line. This embodiment of the invention is based on the realization that the two reduced dosage actual lines 5 and 6 exposed at the 10th and 11th address lines will behave in a diffraction grating in approximately the same way, i.e. effectively, as a full dose effective line half way between the 10th and 11th address lines, i.e. at a 10.5 address line position, where no address grid line can exist. Subsequently a single actual full dose line 7 is written at the 21st address line position which is in fact a desired line position and two more half-dose actual grating lines are written in the grid positions (not visible in Figure 2) determined by the 31st and 32nd address lines. These two are actual lines of the grating, but will behave as an effective line at the 31.5th address line position, where there is no address line. Then there will be another single full dose actual line at the 42nd address line, another desired line position not visible in Figure 2. Thus a 10.5 address line effective grating line spacing is obtained.

If effective lines spaced at a 9.5 address line spacing had been desired, the actual approximately half-line doses would have been written at the 9th and 10th address lines after the datum 0th, and at the 28th and 29th address lines, and full actual line doses at the 19th and 38th address lines.

The combination of two actual closely spaced grating lines into an effective grating line between them depends on the response of film media registering closely spaced gaussian curves.

Evidence that this information on combining unequal or equal line exposure doses can be generated is readily available from standard text books, such as Electron Beam Technology in Microelectronic Fabrication, edited by George R. Brewer, published in 1980.

Analogously, referring to Figure 3, if a grating line is to be effectively written every 10.25 scanning address grid lines, partial dose actual lines are again written at the 10th and 11th address lines, the 20th and 21st, and at the 30th and 31st address lines after the datum defined by the 0th index address line referenced 14. The doses of actual line exposures referenced 9 and 10 at the 10th and 31st address lines are about 0.8 of the full dose. The full dose is given only to actual and effective single lines referenced 14, 13 at the zero and 41st grid line positions as illustrated. The 30th and 11th address line positions are used to expose fractions 0.2 of the full dose. Address grid positions 20 and 21 are both written with half-dose actual lines 11 and 12. The above programme gives the effect approximately of writing one full dose effective line every 10.25 address grid positions as scanned, at which positions no actual strobes exist.

The above analysis is not strictly accurate but gives a fair approximation. The two partial dose lines at consecutive pixels are not exactly equivalent to one line at the proportionate interpolation given for pairs of part-dose lines referenced 11 and 12, or 9 and its neighbour, or 5 and 6, but the principle can be used, and correction, if needed, can easily be performed to predict the exact amount of dosage to provide a given effective spacing correction in more complex situations by means of graded exposure line pairs, with the inherent precision given by use of a standard actual line strobe generator i.e. using the same scanning address grid that can be used for the single exposure lines of Figure 1.

It is also possible to create effective grating lines with spacings corresponding to steps of between 9 and 10, say 9.75 address grid lines by initiating decreasing dose actual lines again from the 0th to the 10th, 20th, 30th and 40th and so on, and increasing actual dose lines at the 9th, 19th and 29th address line positions. Thus the regular effective line spacing is made between 9 and 10 address line spacings.

Although effective address line spacings between 10 and 11 or between 9 and 10 address line spacings, were used in the above examples, there could be deviations of 0.25 or 0.50 or some other fraction from a count of every xth address line, by creating two actual component grating lines of similar relative exposure as for the particular case x=10, starting as shown in Fig. 4 at the xth and (x+1)th address lines referenced 15 and 16; or respectively starting at the xth and (x-1)th address line (not illustrated). Again, as seen in Fig. 4, the xth, 2xth, 3xth actual line doses would gradually decease to (n-1)x referenced 17; and, either the (x+1)th, (2x+1)th, (3x+1)th actual line doses would gradually increase (as shown), or the (x-1)th, (2x-1)th dose would increase (not shown). The effective grating line pitch would be ($x \pm 1/n$), respectively.

Thus if the desired effective line period is to be a little <u>more</u> (i.e. 1/n more) than one line every xth address position, the actual line doses at the x, 2x, 3x, ... nx address line positions will desirably successively decrease from a full dose at the zero address line position to zero dose at the nx position, while the actual line doses at the (x + 1), (2x + 1) ... (nx + 1) address line positions referenced 16, 18 and 19 will correspondingly increase from zero to the full dose in n steps, the total dose at each xth pair of address line positions in one example may correspond (approximately at least) to a full dose for an actual line. Every nth line, there will be a single, approximately full actual dose at an (nx + 1)th pixel position. The effective line spacing is correspondingly increased from x address line spacings by a fraction 1/n. If the successive increases of the doses are not predicted accurately and followed, there may be some degree of undesirable and perhaps unpredictable chirp.

It will be readily seen that analogous logic will apply if it is desired to time lines to be effectively written at something <u>less</u> than that corresponding to x address line spacings, i.e. shorter periods by some regular fraction 1/n. Figure 4 only graphs the dose against address position for increasing desired line spacing effectively to a little <u>more</u> than x address line spacings.

It will also be apparent that the fraction can be selected itself to vary in some, perhaps regular way, up and down in pitch, so that a predictable chirp will result. If the chirp is irregular, then unwanted sidelobes will appear in the resulting diffraction or reflection pattern, so that production of an accurately predictable chirp is of paramount importance.

The examples as described have exhibited two consecutive scanning address grid line positions as timing a sum of two actual doses equivalent to a single dose at an effective position intermediate the two address lines, but it may be advantageous and even more accurate to set up partial actual line doses at three consecutive address line positions, rather than two, in order to make up the equivalent whole line dose where required. However, the complexity of three or more dose components on three or more neighbouring actual lines may not justify its use other than in exceptional circumstances.

Thus it is seen that, in the embodiments that have been described by way of example in illustration of this invention, the inflexibility of even a totally digitized scanned beam regular address structure is no obstacle to selecting different, intermediate addresses, or to providing small accurately predictable chirps whereas prior scanning methods tended towards the production of large chirps.

The examples described above give substantial benefits, and a very close approximation to an accurate solution.

Modelling and experimental derivation may be employed to enable a precise effective position or address to be determined of any combination of irradiation doses in groups of (usually consecutive) address lines. Combinations of these effects can provide greater flexibility in defining both fixed spacing, and simple and complex variable spacings or variable angular spacing (in the case of polar scanning) line or grating structures.

It will be understood that although particular embodiments have been described, by way of example in illustration of the invention, variations and modifications thereof, as well as other embodiments may be made within the scope of the appended claims.

For example, the arrangements described may be applied not only to a grating structure but to any addressing system in which it is desired to access or define addresses intermediate addresses of a given addressing system. An available line of a system may be finely adjusted or varied comparatively easily. Simple, or complex gratings with variable pitch or chirp may be made using arrangements within the scope of the appended claims.

CLAIMS

1. A method of scanning an area under control of a scanning address grid of regular address lines, wherein at least one effective line is created at a position which does not correspond to any address line of the scanning address grid, by initiating actual lines at positions which do correspond to at least two address lines of the scanning address grid.

2. A method as claimed in claim 1 wherein the at least two actual lines are initiated with doses approximately totalling a single full dose.

3. A method as claimed in claim 1 or 2 wherein the address grid is scanned with cartesian or polar actual lines (with parallel or radial lines).

4. A method of scanning an area by means of a given scanning address grid of regular address lines, in which each of some at least of the desired lines are effectively scanned by using a respective group consisting of more than one address line of the address grid to initiate actual lines with less than the full dose but the total dose of initiated actual lines of the group amounting to approximately a full dose, whereby the effective line spacing is varied selectively from a line spacing directly available from the scanning address grid.

5. A method as claimed in any of claims 1 to 4 wherein the desired lines are those of an optical line grating.

6. A method as claimed in any of claims 1 to 5 wherein lower index actual lines of the successive groups are scanned with a gradually increasing dose from group to group and higher index actual lines of the successive groups are scanned with a gradually decreasing dose from group to group; or vice-versa (as regards decreasing and increasing and lower and higher index lines).

7. A method of writing a line grating by means of a scanning address grid of equispaced parallel address lines, the line grating having effective parallel lines at spacings ($x \pm 1/n$) units of the address line spacing, where x and n are integers, effective grating lines thereby not corresponding in position to address grid lines, including the steps of initiating pairs of actual line components to occur at successive pairs of two consecutive address line positions x, $x \pm 1$; $2x$, $2x \pm 1$; $3x$, $3x \pm 1$; ....nx, $nx \pm 1$, the address line positions and hence the writings of actual grating line components of each pair positioned before and after a respective one of the desired regular effective line positions of the grating, grading in normalized steps of approximately $1/n$ the dosage of successive actual line components of those of each pair positioned before respective address lines, and grading in normalized steps of approximately $1/n$ the dosage of successive line components of those of each pair positioned after respective address lines, the grading of the latter dosage being approximately complementary to the former grading, such that the dosage of the line components of each pair sums to approximately the effective dosage of the desired effective regular grating lines, when and if appropriate writing single actual lines at actual address line positions (e.g. 0, $nx \pm 1$) with full dosage, whereby a scanning address grid having some lines at x units and multiples of x units of the address line spacings is applied to create effective grating lines at an effective spacing of ($x + 1/n$) or ($x - 1/n$) units of the address grid line spacing.

8. A line grating in which the majority of effective single lines with effective positionings are provided each by two or more actual lines at given grid address line positions and different dosages which two or more lines combine in effect to give the effect of a full dose appropriate for a single effective line at the desired effective positioning not coincident in general with any address line position.

9. A method or line grating as claimed in any of claims 1 - 8 and substantially as hereinbefore described with reference to Fig. 2, 3 or 4 of the

accompanying drawings.

10. A line grating when scanned or written by the method of any preceding method claim.

11. A fibre optical waveguide line grating comprising groups each of two or more actual lines at some of a series of regularly spaced positions, the actual lines being generally of different intensities, such that each group of actual lines simulates an effective line at a position not being one of the series of positions.

12. A grating as claimed in claim 11 installed in the wall of the waveguide such that the grating lines are spaced along the axis of the fibre optical waveguide.

13. A grating as claimed in claim 11 or 12 wherein the positions of the effective lines are such that a degree of chirp is exhibited by small and precise irregularities in these positions.

14. A grating as claimed in claim 13 in which successive effective line spacings each exhibit a fraction more or less than the preceding effective line spacing, wherein the fraction is related to the regular series of positions, the fraction being slightly modified from being a regularly increasing or decreasing fraction by small amounts defining the chirp in the effective line positions.

The Patent Office

15

Application No:	GB 9803057.0	**Examiner:**	Peter Easterfield
Claims searched:	1 to 14	**Date of search:**	30 June 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): G2J (JGFG); H4T (TATX)

Int Cl (Ed.6): H01J 37/30, 37/302, 37/305

Other: Online: WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	WO 97/22023 A1 (BRITISH TELECOMMUNICATIONS)	11
X	WO 94/28574 A1 (ETEC)	1,4,7 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.